A 21st Century Approach to Reliability Program Overview

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Outline

- Research Thrusts - Talk Organization
  - Fabrication, Statistical Support
  - Materials and Electrical Characterization
  - Modeling and Simulation
- Issues
  - Early Failure
  - Failure Identification and Understanding
  - Improved Testing
- Collaborations

Research Thrusts - Support

- Fabrication - Pearton
  - Several Industrial Partners
  - Like to have more!
  - Local Fabrication capability for hypothesis testing
- Statistical Support - Pearton, Law
  - Collaborate w/ Intel Reliability Team
  - Work with best Si techniques / approaches

Raytheon

WIN SEMICONDUCTORS

RFMD

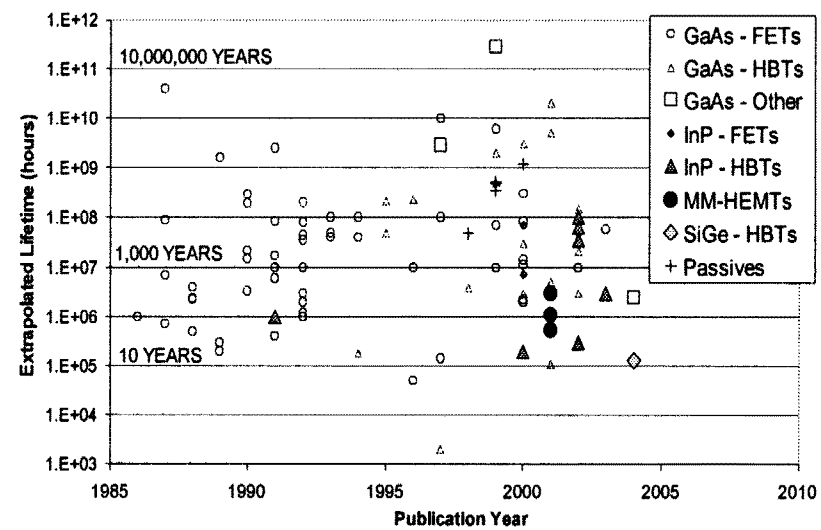


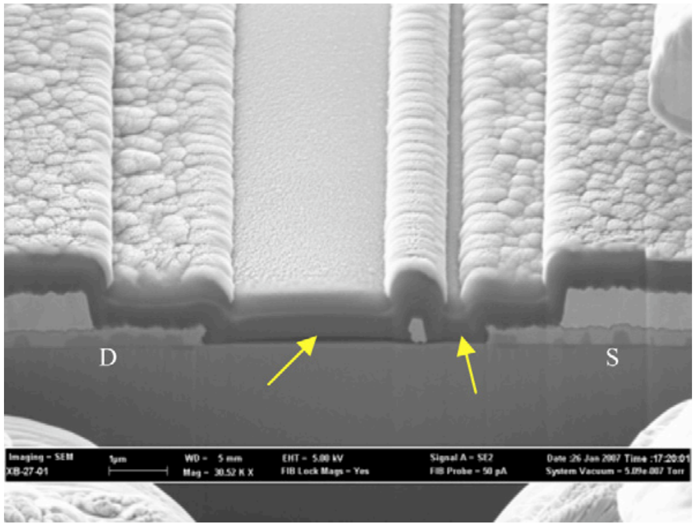
FIGURE 1. REPORTED OPERATING LIFETIMES FOR VARIOUS COMPOUND SEMICONDUCTORS OVER THE 19 YEAR HISTORY OF THE ROCS WORKSHOP[1]

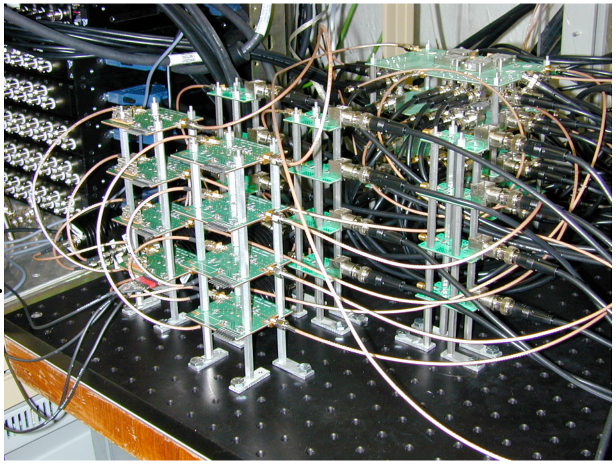
Roesch, 2006

Research Thrusts - Primary

- Materials Characterization - Abernathy
  - Optical Techniques, Electron Microscopy, LEAP
- Electrical Characterization - Thompson
  - Burn-in, Stress, Noise
- Modeling - Law
  - TCAD Extended Approaches, Noise, Stress

SEM
Gate
Sink

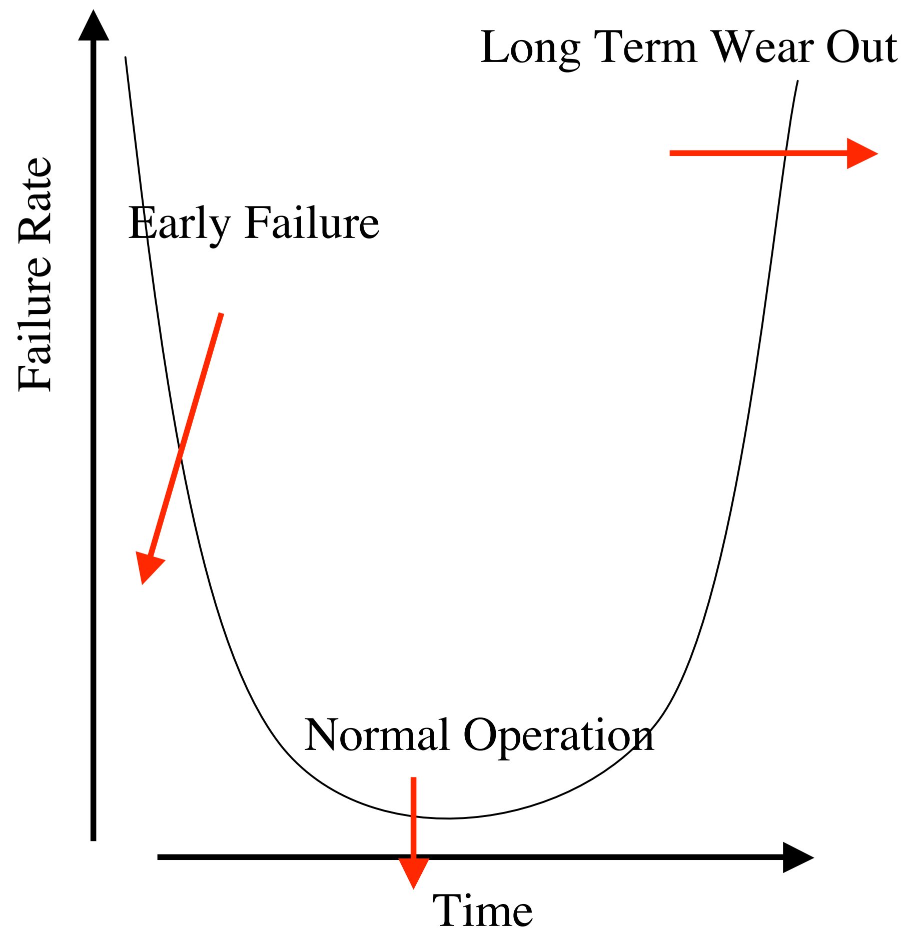




Provide DC and RF Power
Thermoelectric Heating
Measure:
Gate/Drain Current
Forward, Reflected, and Output Power

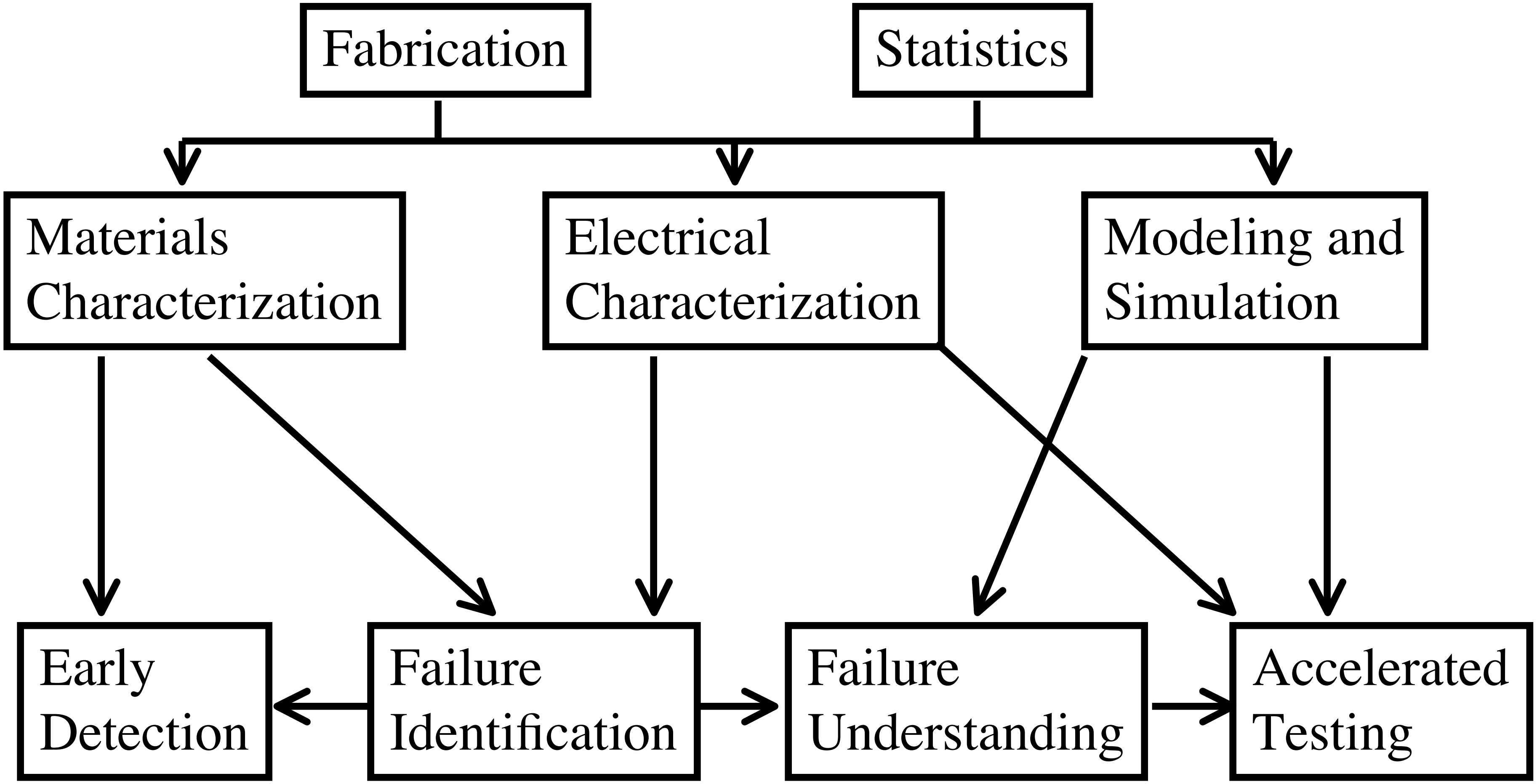
Electronic Lifetime - Bath Tub Curve

- Industry Objectives
  - Reduce Early Failure
  - Reduce Random Failure
  - Length time to Wear Out
- MURI Research
  - Develop Prescreen Tools
  - Provide Understanding of Failure to reduce random components
  - Identify causes of long term wear
  - Develop better accelerated testing



Push the curve in the red directions

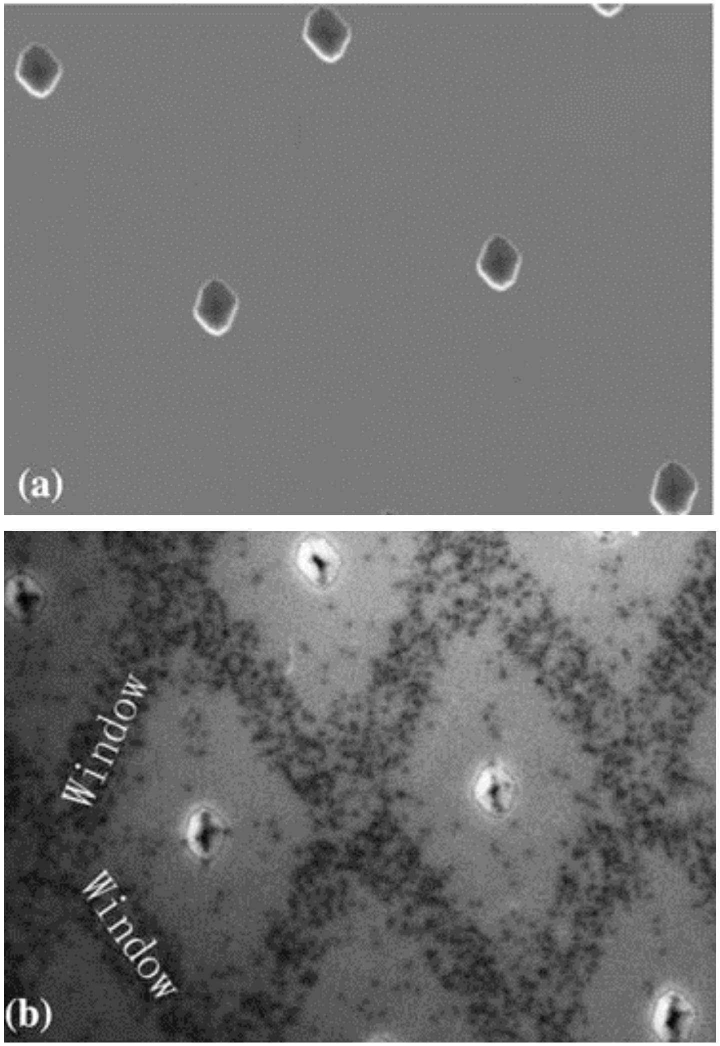
Thrust to Problem Relationships



Early Failure Identification - CL

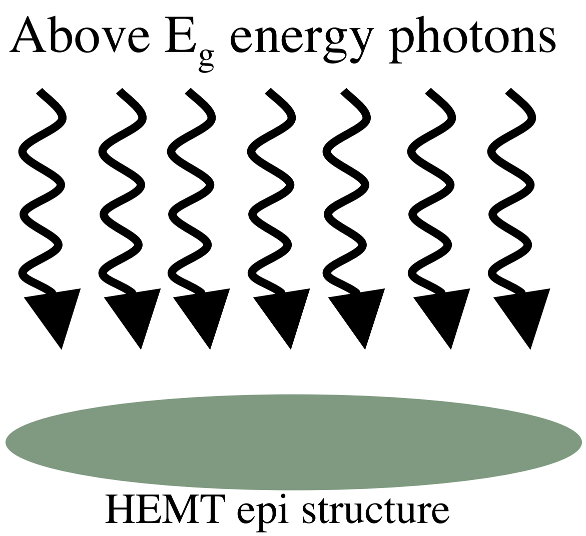
- Plan view scans of device regions after degradation
- Remove metal after various processing steps and after failure
- Correlate changes in spatial distribution with EDS to investigate relationship between metal migration and failure
- Can also be done in cross-section
- Example: examine effects of threading dislocations

- Can we correlate these signals to potential early failure?

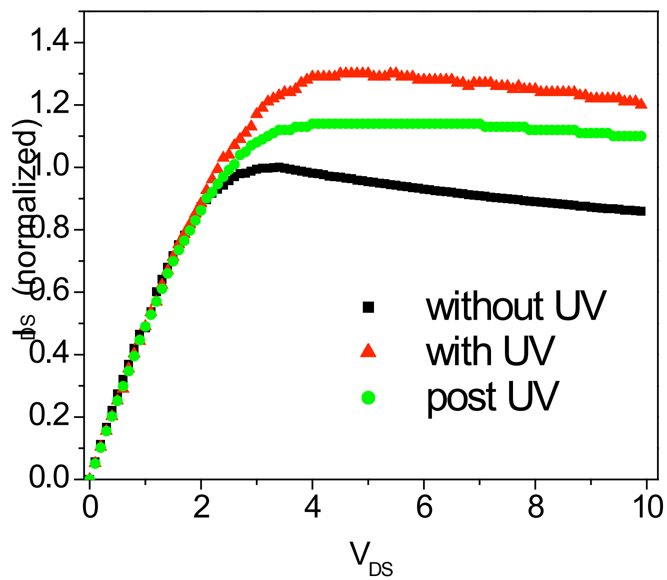


D. S. Jiang et. al., J. Mater. Sci., 2008.

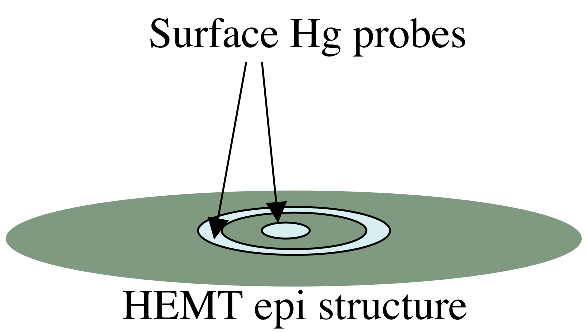
Early Detection - Photo-pumping Traps and Recovery



Above E_g energy photos empty e^- traps, cause the carrier conc. to increase.



Employ a Hg probe CV technique to monitor refilling of traps.

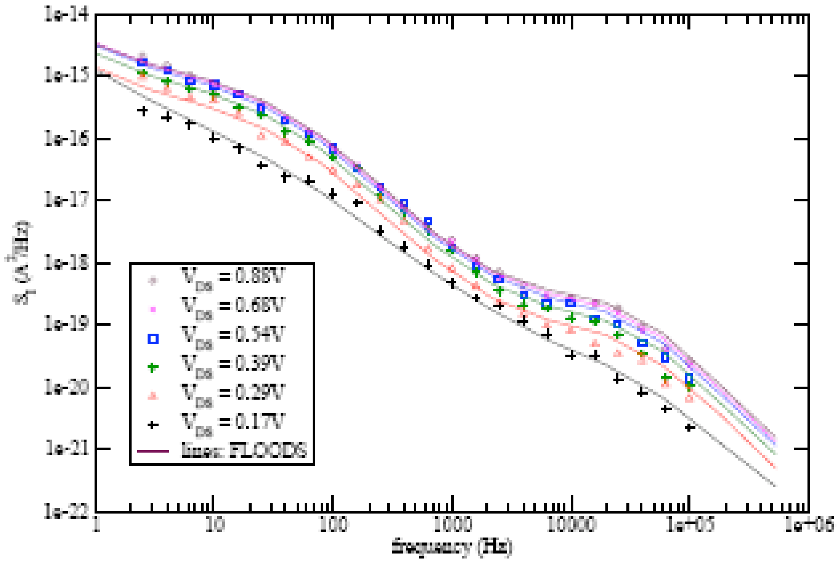


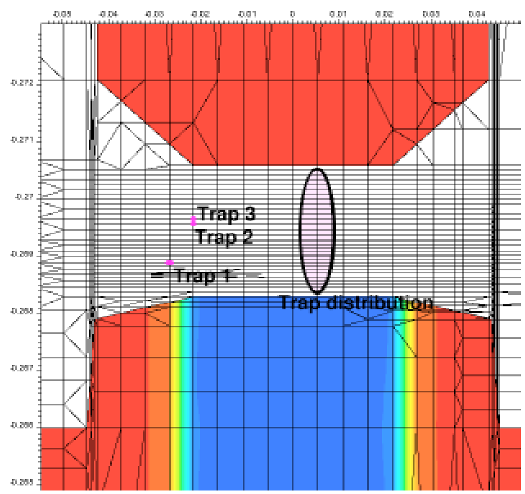
Pre-test I_{ds} current recovers in ~3 days.

Use data to construct trap metrics and screen epi material.

Early Detection - Noise

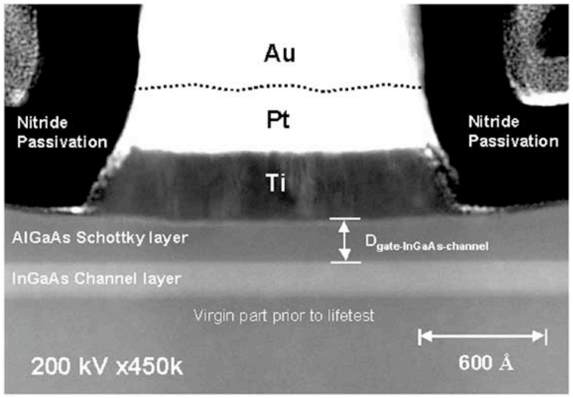
- Noise Signal Correlates with traps
- Monitor noise signal with burn-in condition
- Trap Generation should be observable in noise
- Can we correlate initial trap related noise to final failure?



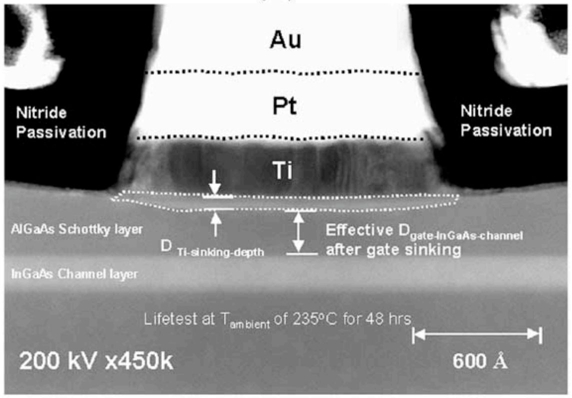


Failure Identification - STEM

- Cross section Scanning Transmission Electron Microscopy (STEM) combined with EDS
  - electron optics focus beam into spot which is scanned over the sample in a raster.
  - rastering enables mapping by EDS
  - possible to form atomic resolution images where the contrast is directly related to the atomic number (Z-STEM).
- FIB sample preparation
- Identification of subsurface changes responsible for failure
- TEM 2210 with EDS



(1a)



(1b)

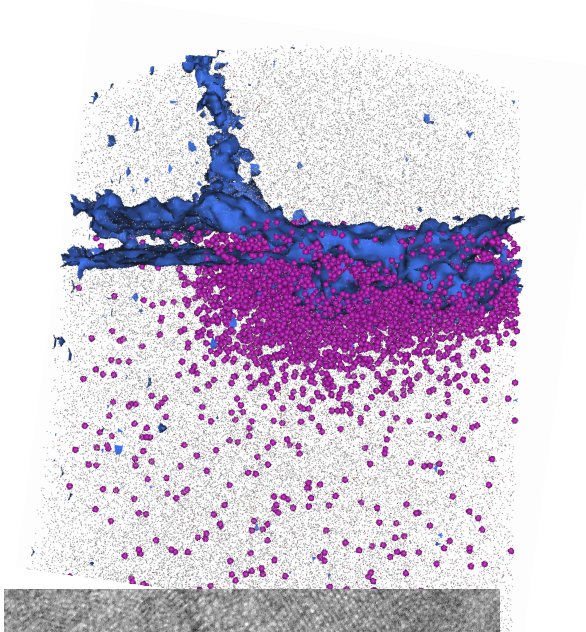
Example of GaAs Gate Sinking

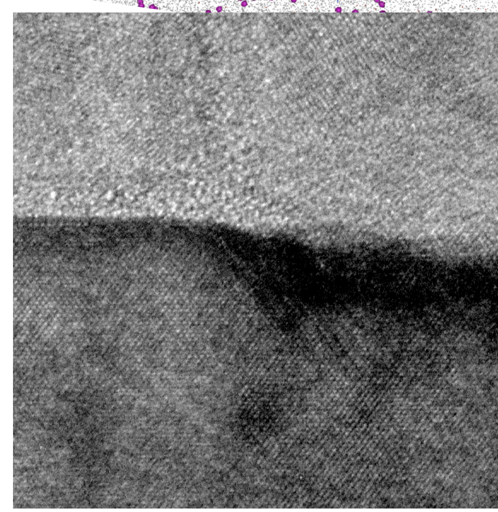
Y.C. Chou, et. Al., IEEE Device Lett.25 (2004)

Failure Identification - LEAP

- Local Electrode Atom Probe
  - 3D Mapping of atoms
  - Atom by Atom resolution
  - 0.2nm resolution
  - TOF SIMS mass resolution
  - 10^7 atoms in sample
  - FIB Based Prep
- Identification
  - Surface reactions
  - Metal migration

  ???

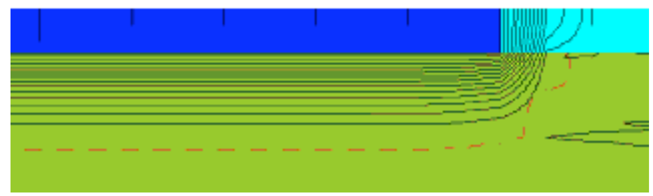


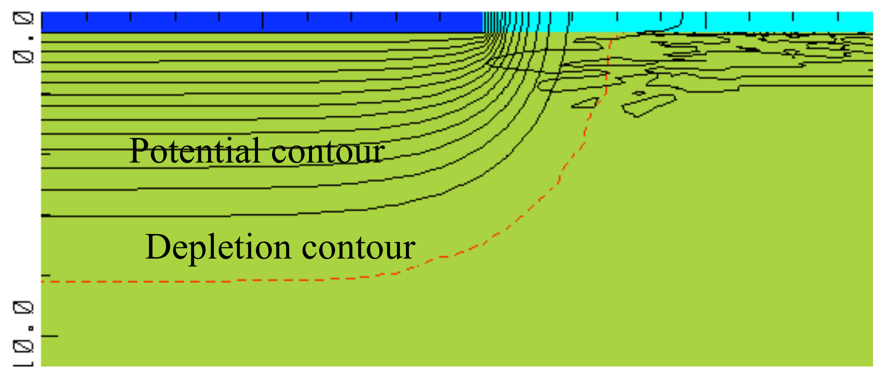


Failure Understanding - Modeling

- Simulate Device in Quasi-Steady State
  - Electrons and Holes equilibrate quickly
  - Similar to assumption in process simulation
- Generation Events Triggered by
  - Mechanical Stress
  - Current Flow / Electric Field
- Simultaneous solutions
  - Point Defects / Defect Cluster / Interface Capture
  - Hydrogen
- Better Models -> Better Failure Prediction

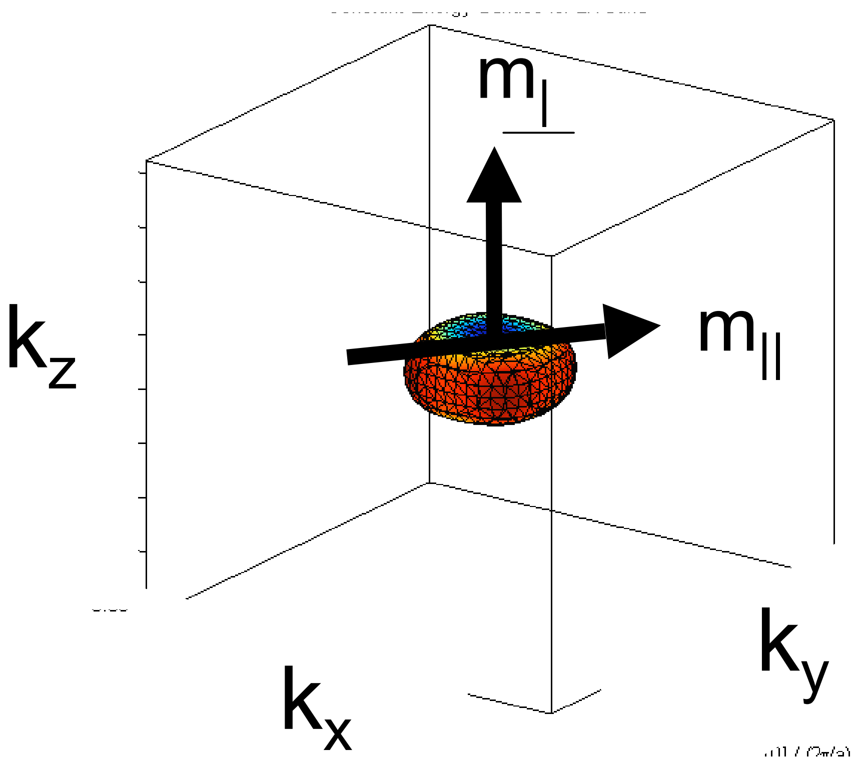
Operator	*Description*
"ddt"	Time derivative
"grad"	Spatial derivative
"sgrad"	Scharfetter / Gummel Discretization Operator
"dot"	Returns the dot product of the gradient of two field – electric field in direction of current floq
"elastic"	Compute elastic forces - FEM balance



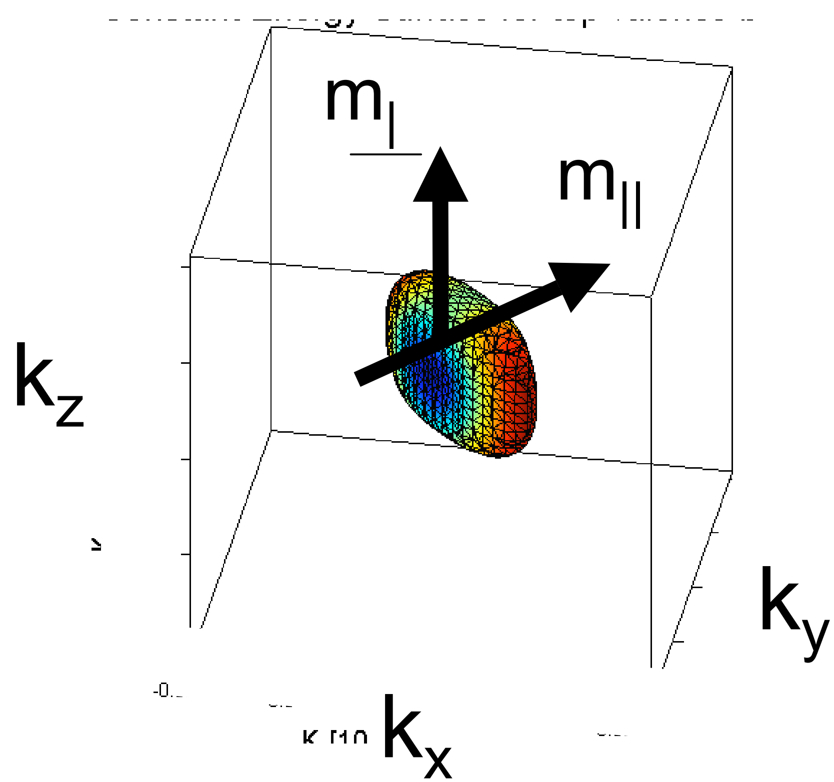


Failure Understanding - Mechanical Strain

Biaxial Stress



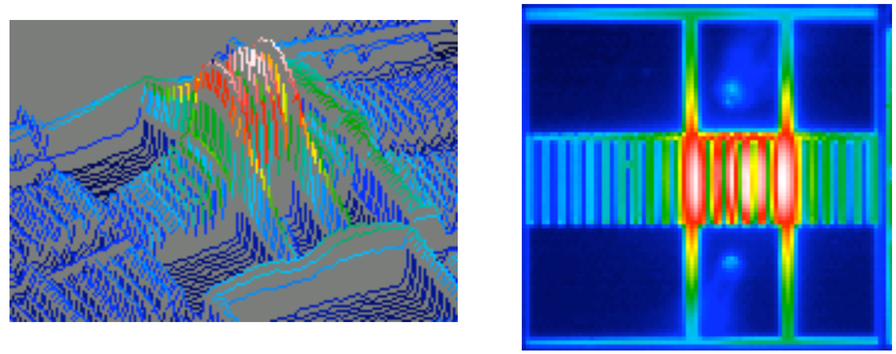
Uniaxial Stress



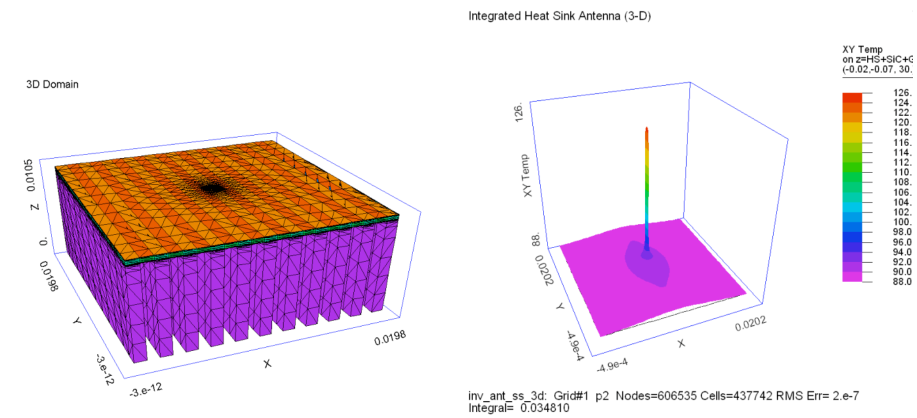
Using k•p methods to compute bands

Accelerated Testing - Temperature Verification

- Critical to extract actual device operating temperature
- Combination of modeling and thermal imaging
- Develop model for Temperature distribution in testing conditions



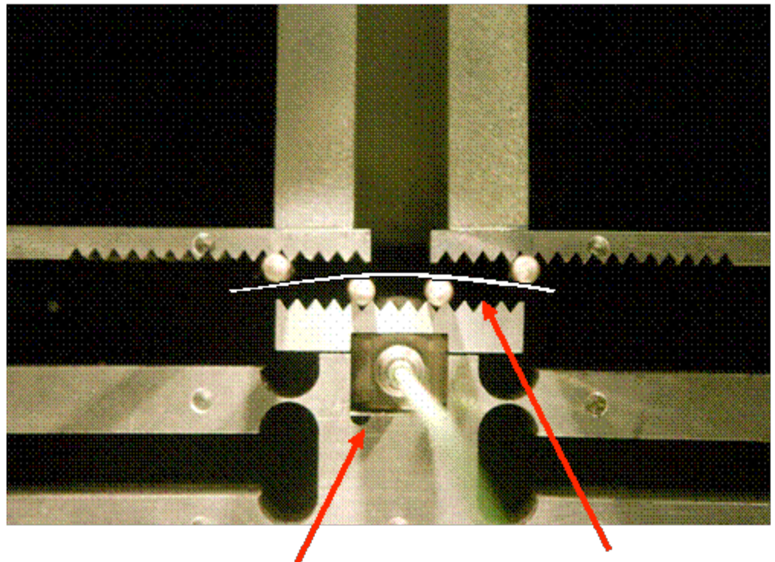
Thermal Imaging w/ μRaman

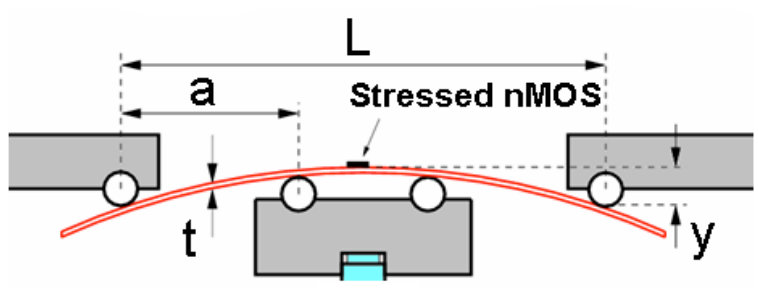


3D Thermal Modeling

Accelerated Testing - Strain

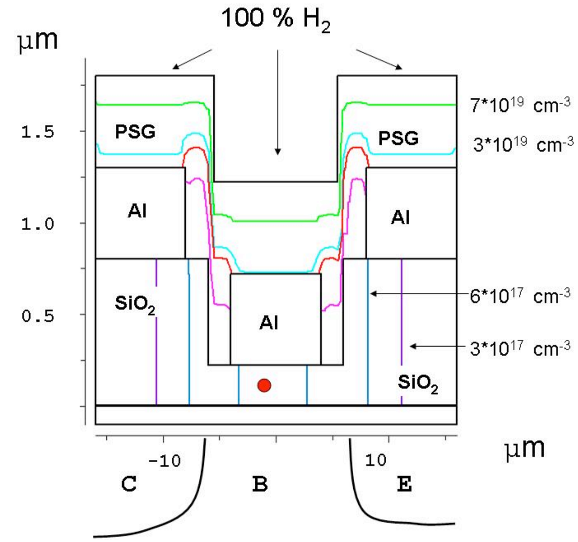
- Strain Bending Rig
- Allows an External Strain to be added to device
- Strain enhances failure
- Acceleration with strain, temperature, field
- Probe of Inverse Peizoelectric effect



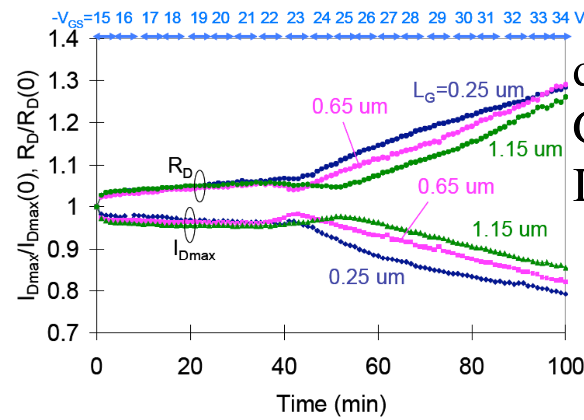


Possible Collaborations w/ DRIFT

- Vanderbilt
  - Surface Degradation
  - Hydrogen Behavior During Device Operation
  - Existing Collaboration on Radiation Effects
- MIT
  - Overlapping Interest in Stress
  - Share data and models
- Modeling
  - NC State / Michigan have different approaches
  - Leverage across programs



TNS, TBP



del Alamo Group, 2006 IEDM

Fig. 11. Gate length dependence of degradation. Different gate length devices (type A1, L_G=0.25, 0.65, and 1.15 um) are stressed at V_{DS}=0 and V_{GS}=-15~-34 V (-1 V step, 5 min/step). The threshold of the degradation increases with L_G.

Conclusions

- Science Based Program
- Directed at:
  - Failure Analysis - pinpoint causes
  - Early Detection of Failures (Prescreen tests)
  - Better Models of Degradation
  - Better Prediction of Failure
- Strong Collaborations